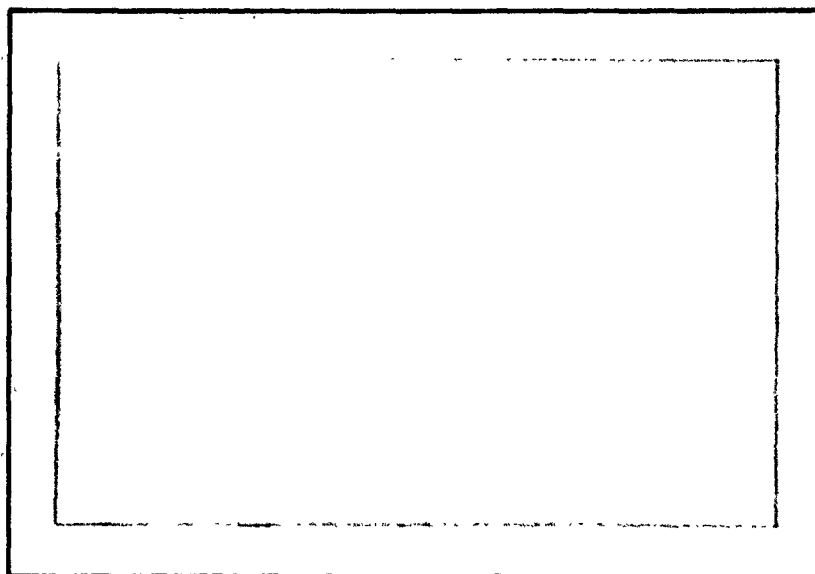


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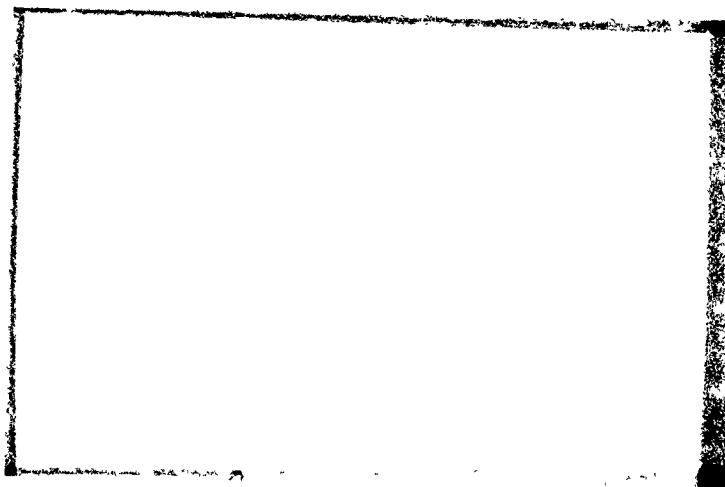
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N. Fukuta
V. K. Saxena

Denver Research Institute
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ABSTRACT

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During the last one-year period, a field version of *this laboratory's* Cloud Condensation Nucleus (CCN) Spectrometer-capable of continuously monitoring and displaying in real-time the activation spectrum of fog and cloud nuclei was fabricated and field-tested. The tests proved it to be a dependable field instrument. In July, 1975, the CCN Spectrometer was installed aboard U. S. Naval Ship Hayes for measuring the characteristics of aerosols that participate in the marine fog formation. The spectrum measurements were made during a three-week-long cruise aboard the ship off the coasts of Nova Scotia and Newfoundland. Some two thousand spectra were measured while approaching the fog, in the fog, and getting out of the fog. A variety of fog conditions were encountered in the field. A comparison of the CCN spectrometer data was also made with the data obtained by the NRL (Naval Research Laboratory) chamber. The agreement between our spectrometer and the NRL chamber was found to be the same as the agreement between the latter and other static thermal diffusion chambers compared so far.

Our field measurements demonstrate that the fog nuclei spectrum in the supersaturation range of 0.15-1.2% undergoes a marked change at the fog boundaries. This is exemplified by a case study of the fog that occurred in the early morning hours (2:00 A.M. - 8:00 A.M.) of August 6, 1975, off the Nova Scotia coast. The fog nuclei concentration within the dissipating fog boundary was found to be much lower than that at the forming boundary. The fog appeared to be an efficient scavenger of nuclei active at 1.2% supersaturation and below. The slope of the spectrum, which is one of the important parameters in modeling microphysical interactions, also registered a profound change at the forming boundary. The fog nuclei concentrations at the forming boundary were typical of continental aerosols that evidently participated in the marine fog formation. It is pointed out that for evolving a precise model for predicting fog visibilities, microphysical interactions will have to be considered along with kinetic and thermodynamic interactions. Our measurements constitute one of the parameters of consequential importance in delineating microphysical interactions.

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1. INTRODUCTION

The physical processes which interact to produce fogs are varied and complex. For example, the marine advection fog forms when a shallow layer of moist air, trapped beneath an inversion, moves from a region of warm ocean surface temperature to a region of colder surface temperature. The downward transport of thermal energy in the moist layer leads to formation of a region of supersaturation near the ocean surface and formation of fog. Subsequently, the fog may be intensified by further heat losses due to radiative cooling.

The essential physical processes in a macroscopic sense are the fluxes of heat and moisture across the air-sea interface and the rates of vertical transport of heat and moisture by eddy and molecular diffusion processes. The presence of a low-lying inversion is crucial because it acts as a barrier to upward vapor transport, thus allowing the boundary layer to accumulate moisture until the saturation level is reached. Radiative cooling will tend to accentuate the inversion once the fog has formed.

A number of numerical models have been developed to describe marine fog formation in terms of these macroscopic processes (Fisher and Caplan, 1963; Mack et al, 1972; Barker, 1973). We shall denote such models as "thermodynamic" models, since they assume a state of thermodynamic equilibrium between liquid water and water vapor wherever the total concentration of water substance exceeds the liquid saturation level. In other words, a supersaturated condition is never permitted to exist. Such models are useful for investigating the conditions under which fog may form. However, they provide no information on the properties of the fog, other than an estimate of its liquid water content.

The most important aspect of fog as it affects naval activities is the reduction of visibility it produces. Visibility in fog depends entirely upon the number concentration and size distribution of the hydrometeors comprising it. Thermodynamic models cannot describe these properties; they can only be determined by considering the kinetics of hydrometeor formation, growth, and evaporation. A model which couples

the thermodynamic description with the rates of microphysical processes is required if we wish to investigate the fog droplet size distribution in space and time. We shall refer to such models as "kinetic" models. A kinetic model provides the information required to predict fog visibilities, and also permits a quantitative investigation of fog modification possibilities. Such a model is highly desirable, and does not exist for marine fog at this time. We (Fukuta, 1973, 1974) have already analyzed physical interactions in the simplified air slab model, with a constant eddy diffusivity. As a result of this analysis, it was clearly demonstrated that the measurement of fog nuclei spectrum, particularly at the upwind fog boundary, constitute an essential input parameter for predicting fog visibilities.

2. ACCOMPLISHMENTS

Before proceeding to analyze the spectrometer data, it is in order to comment on what and how the measurements are made. The principle of the spectrometer was discussed by Fukuta and Saxena (1973a), the details of a preliminary working design were described by Fukuta et al. (1974), and Saxena and Fukuta (1974), and a field version of the spectrometer was presented by Fukuta and Saxena (1975). Recently, the merits of the spectrometer were also stressed by Veal et al (1975). From these discussions, it is clear that the spectrometer produces an activation spectrum of fog or cloud nuclei in a desired supersaturation range ($S_{\min} \geq 0.15\%$) at as short a time interval as 15 seconds. The resulting activation spectrum is displayed by an X-Y recorder. For counting the activated nuclei, each droplet bigger than the threshold size is counted individually as soon as it passes through the sensitive volume of the Climet CI-201 Particle Analyzer and instantaneous droplet counts are registered. The rate at which the droplets pass through the detection volume determines the droplet concentration. For example, a smaller time interval between two droplets passing successively through the sensitive volume would correspond to a higher concentration.

2.1 Comparison with the NRL static chamber

Three thermal diffusion chambers, namely the NRL static chamber, the DU continuous-flow spectrometer, and the UMR (University of Missouri-Rolla) vertical flow chamber participated in the Marine Fog Field Expedition of 1975. The opportunity was also utilized to make comparison between the data produced by the three instruments. The comparisons were made aboard the U. S. Naval Ship Hayes by using natural aerosol as the test sample. A total of 12 comparison runs was made. The test aerosol was filled in a 220 liter capacity aluminized mylar bag which supplied the sample to each instrument for comparison purposes. Total time taken by the three instruments for one comparison run was typically less than 20 minutes. In order to avoid biasing the data, the observations of all comparison runs were exchanged on a set date, namely, October 1, 1975, so that the operators of these instruments were unaware of the results produced by the other two. These data are reproduced in Table 1.

The NRL counts in Table 1 represent the average of a few runs made at a given supersaturation. These values are individually reported in Table 2. Table 3 typically represents the state-of-the-art of inter-comparison as of August 1970 when a major comparison program was undertaken at the second IWCIN (International Workshop on Condensation and Ice Nuclei). Experiment #27 is chosen here because it was also selected for the summary (Ruskin and Kocmond, 1971). Without exactly knowing the state-of-the-art, comments for any comparison cannot be put into proper perspective.

In Table 4, the state-of-the-art of comparison for CCN counters has been updated, including our recent data from the dynamic chambers of DU and UMR. In column 1 of this table, the concentration ratio interval of 0.4 has been arbitrarily chosen in order to underscore the salient points of comparison. In Fig.1, the data of Table 4 is pictorially presented.

Considering the above data, the following conclusions seem to be reasonable.

Table 1

Summary of measurements made aboard HAYES for comparison purposes (Data exchanged on October 1, 1975)

Run No.	S %	NRL cm ⁻³	DU cm ⁻³	UMR cm ⁻³	Conc-ratio (NRL/Other)	
					DU	UMR
1*	0.3	4520	1060	-	4.3	-
2*	0.5	5167	2119	-	2.4	-
3	0.3	1421	282	228	5.0	6.2
4	0.75	996	-	357	-	2.8
5	0.4	1146	671	324	1.7	3.5
6	0.5	1347	635	534	2.1	2.5
7†	0.15	114	106	37	1.1	3.1
8	0.15	577	353	85	1.6	6.8
9	0.25	1062	1412	239	0.8	4.4
10	0.25	-	280	63	-	-
11	0.5	1135	1766	391	0.6	2.9
12	0.35	1203	530	377	2.3	3.2

*The DU spectrometer was set up to measure a maximum concentration of 3,500 cm⁻³ only. For these two runs, the DU counts are not representative of actual CCN concentration.

†The scatter in the NRL data was of the order of a factor (Max. value/Min. value) of 2.5 that is also the maximum scatter reported.

Table 2

Comparison between CCH concentration recorded by the NRL static thermal diffusion
chamber, the DU spectrometer, and the vertical parallel-plate chamber of UMR

Run No.	Collection	Date	f ₂	NRL Measurements			DU Measurements			Average of NRL & DU, i.e., $\frac{g+h}{2}$	% Error from the average $\left \frac{g-h}{1} \right \times 100$ or $\left \frac{h-1}{1} \right \times 100$	UMR Conc. cm ⁻³	Ratio Col. a Col. k	Ratio Col. l Col. k
				Conc. cm ⁻³	Maximum Scatter ^a	Average conc. cm ⁻³	conc. cm ⁻³	Maximum Scatter ^a	Average conc. cm ⁻³					
		a	b	c	d	e	f	g	h	i	j	k	l	m
3		8/1/75	0.30	947 ^x 1,150 ^x 1,465 ^x 1,580 ^x 1,243	50%	1,471 (1,288) [†]	282 353 706	86%	447	934	52%	228	6.2	4.1
4		8/2/75	0.75	-	-	996	DU did not participate			996	-	357	2.8	2.8
5		8/2/75	0.4	1,199 1,154 1,051 [*] 1,228 1,095	16%	1,146	671 741	10%	706	926	24%	324	3.5	2.9
6		8/3/75	0.5	1,302 1,036 [*] 1,643 1,421 1,332	45%	1,347	635 671 706	11%	671	1,009	33%	534	2.5	1.9
7		8/4/75	0.15	118 [*] 89 89 148 148 148 57	86%	114	106 88	19%	97	106	8%	37	3.1	2.9
8		8/4/75	0.15	554 [*] 459 [*] 552 607 636	32%	577	353 494 530	40%	459	518	11%	85	6.8	6.1
9		8/5/75	0.25	1,184 725 1,197 [*] 1,154 1,110	49%	1,062 (1,074) [†]	1,412 1,099	29%	1,236	1,149	8%	239	4.4	4.8
10		8/5/75	0.25	NRL did not participate			280 353	23%	317	317	-	63	-	5.0
11		8/6/75	0.5	918 1,021 1,347 1,584 [*] 1,228 918	53%	1,135 (1,169) [†]	1,766 1,432	22%	1,589	1,362	17%	391	2.9	4.1
12		8/6/75	0.35	1,317 1,006 [*] 1,302 1,006 1,391 1,337	32%	1,203 (1,223) [†]	530 635 671	12%	612	908	33%	377	3.2	2.4
Pertinent Average:				45%			31%			23%		3.9		3.7

^a The maximum scatter was calculated as follows:
For example, for Run #7 of NRL, Maximum scatter = $\frac{(148 - 57)}{\left(\frac{148 + 57}{2}\right)} \times 100 = 86\%$

[†] The average concentration is calculated from the data points of column c
and does not agree with the average value reported by the NRL personnel.

^{*} In Figure 4, these numbers are plotted on abscissa.

Table 3

Concentration measured by the participating static thermal
diffusion chambers at the Second IWCIN (August, 1970)
Reference Experiment #27, natural aerosol, S = 0.3%

Run No.	1	2	3	4	5
Chamber	NRL (Film)	NRL (TV)	CALspan Corp.	Univ. of Washington	White Sands (U.S. Army)
Conc., cm^{-3}	262	187	128	117	107
Conc. ratio (NRL/Other)	1	1.4	2.05	2.2	2.4

1. Out of ten comparison runs made with the DU spectrometer, 80% of the runs agreed with the NRL chamber within a ratio range (NRL/DU) of 0.6 to 2.4 (Table 1 and 4). Putting it plainly, if NRL measures CCN concentration as 100 cm^{-3} , the probability of DU measuring it in the range of 167 to 43 cm^{-3} is 80%. At the same time the UMR will record this concentration as 40 only 11% of the time (Fig. 1).

2. To put the above statement in proper perspective, the results of the second IWCIN (Table 3) show that four participating static thermal diffusion chambers agreed with the NRL chamber within a factor of 2.4 (Experiment #27, Natural Aerosol, IWCIN Proceedings, data on p. 126 and graph on p. 94 for 0.3% supersaturation). That is, if the NRL chamber counts CCN as 100 cm^{-3} , other chambers may count it as 40 to 100 cm^{-3} for 80% of the time. This is clearly brought out in Table 4.

3. That the NRL counts may be lower than the other chambers was also reported during the second IWCIN. The CAL (Calspan Corp.) chamber counted higher by a factor of 1.54 (or 154%) and the NOAA (formerly ESSA) chamber counted higher by a factor of 1.36 (or 136%). Reference is made to Experiment #27, natural aerosol, $S = 1\%$, data on p. 126 of IWCIN Proceedings (Ruskin and Kocmond, 1971).

4. Thus, on the basis of the above three statements, it can be said in general, that the agreement between the DU spectrometer and the NRL chamber is about the same as the agreement between the NRL chamber and other static thermal diffusion chambers compared so far.

5. The vertical flow type UMR chamber records consistently low values of CCN concentration. The ratio of NRL/UMR is in the range of 2.5 to 6.8. This ratio is larger at lower supersaturations and vice versa (Table 2).

6. The ratio of NRL to DU counts exhibits no trend with respect to supersaturation. This is because the scatter within the NRL data is by a factor of 2.5 at 0.15% supersaturation and varies randomly with respect to supersaturation (column #4 of Table 2). Since the DU spectrometer is completely automatic, its relative reliability is very high. There is no manual error that affects its interconsistency.

Table 4

Comparison between the extent of agreement between the NRL static thermal diffusion chamber, the DU spectrometer, and UMR vertical parallel-plate chamber, and the participating static chambers at the Second IWCIN

Concentration ratio (NRL/Other) interval	DU			UMR			Second IWCIN		
	No. of runs	% of total runs	Cumulative frequency	No. of runs	% of total runs	Cumulative frequency	No. of runs	% of total runs	Cumulative frequency
0.6 - 1.0	2	20	20	0	0	0	0	0	0
1.0 - 1.4	1	10	30	0	0	0	2	40	40
1.4 - 1.8	2	20	50	0	0	0	0	0	40
1.8 - 2.2	1	10	60	0	0	0	2	40	80
2.2 - 2.6	2	20	80	1	11	11	1	20	100
2.6 - 3.0	0	0	80	2	22	33	0	0	100
3.0 - 3.4	0	0	80	2	22	55	0	0	100
3.4 - 3.8	0	0	80	1	11	66	0	0	100
3.8 - 4.2	0	0	80	0	0	66	0	0	100
4.2 - 4.6	1	10	90	1	11	77	0	0	100
4.6 - 5.0	1	10	100	0	0	77	0	0	100
5.0 - 5.4	0	0	100	0	0	77	0	0	100
5.4 - 5.8	0	0	100	0	0	77	0	0	100
5.8 - 6.2	0	0	100	0	0	77	0	0	100
6.2 - 6.6	0	0	100	1	11	88	0	0	100
6.6 - 7.0	0	0	100	1	11	100	0	0	100
Σ	10	100		9	~100		5	100	

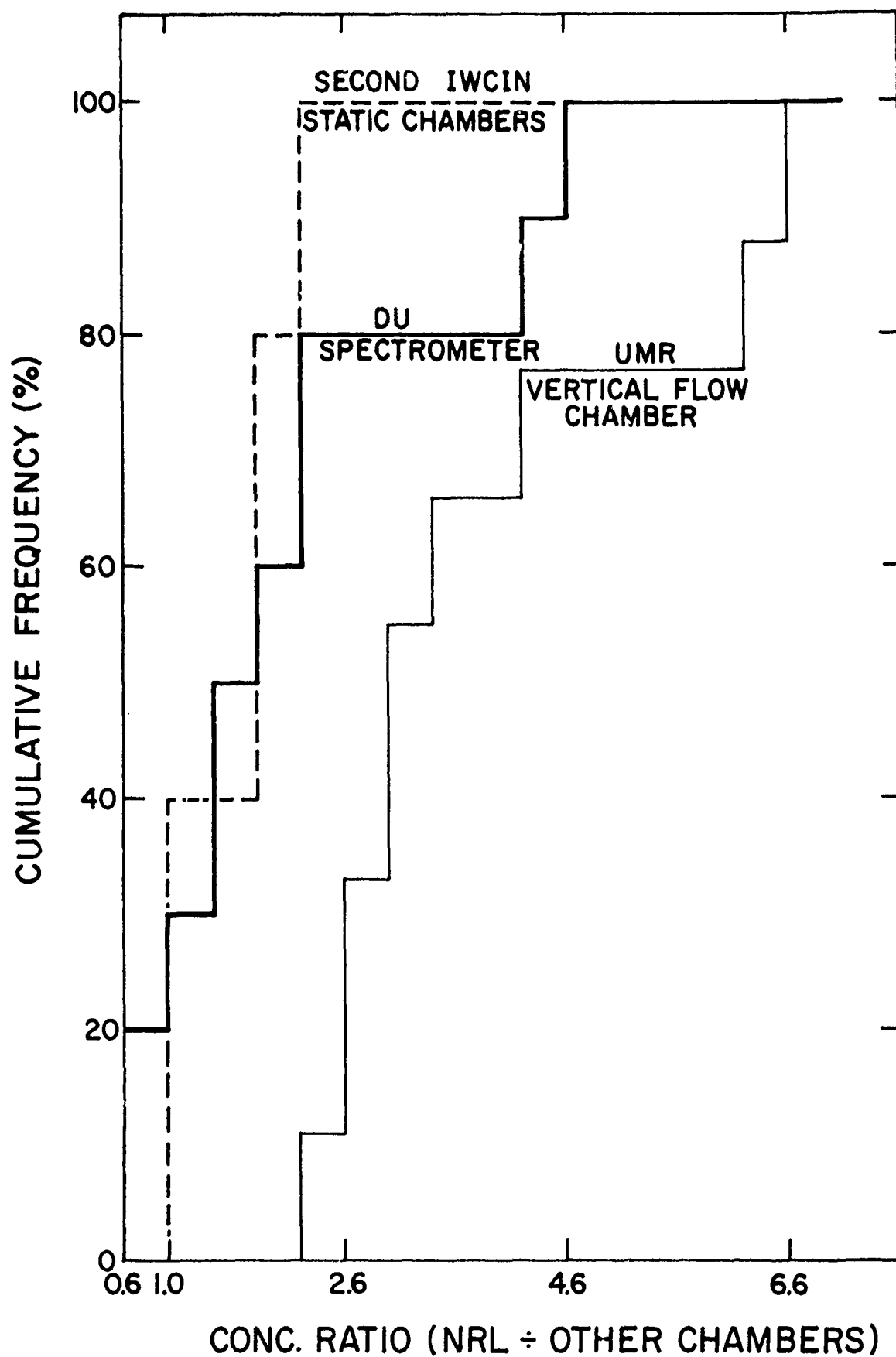


Fig. 1. A summary of comparison of other CCN instruments with the NRL static chamber

7. Runs #1 and 2 are not included in Table 2 as the DU Spectrometer was set up to measure concentrations up to $3,500 \text{ cm}^{-3}$. If the concentration exceeds this value, the sample should be diluted in order to get rid of the vapor depletion problem. It was not anticipated that the marine aerosol would present CCN beyond $5,000 \text{ cm}^{-3}$ at 0.5% supersaturation, and therefore the sample was injected without dilution. For these two runs, the scatter in the NRL data is $\sim 20\%$ and this indicates that the actual concentration was $\sim 5,000 \text{ cm}^{-3}$ and predilution of the sample was needed. Therefore, the values reported by the spectrometer cannot be taken as representative of actual CCN concentration.

8. The analysis of the data presented in Table 2 was done following Ruskin and Kocmond (1971). It is very gratifying to note that for eight comparison runs presented in the table and Fig. 2, the CCN concentration is within $\pm 23\%$ of the average value.

9. Run #3 was particularly bad from the viewpoint of the scatter in the data. The NRL reported a scatter of 50% for five measured points and we reported a scatter of 86% for three points (Table 2). The aerosol was room air and it is suspected that it may not be uniform in concentration throughout the volume of the mylar bag.

10. Out of eight comparison runs (Table 2), our spectrometer recorded CCN concentration higher than that of the NRL values for two runs (#9 and 11) and lower in six runs. Thus, there is no tendency to record consistently lower CCN concentration by our spectrometer.

11. Figure 2 shows all the data points plotted for the eight runs of Table 2. Reasonable values of scatter are attached to each data point. As is readily evident from this figure, the NRL and DU values lie within $\pm 23\%$ of the average concentration.

12. The comparison presented in Table 2 and Fig. 2 is more representative of a realistic situation than Table 1, as the latter compares the average NRL values with the instantaneous DU values and is, therefore, questionable. If the CCN concentration varied within the test sample, the DU values would show instantaneous concentration while the NRL values

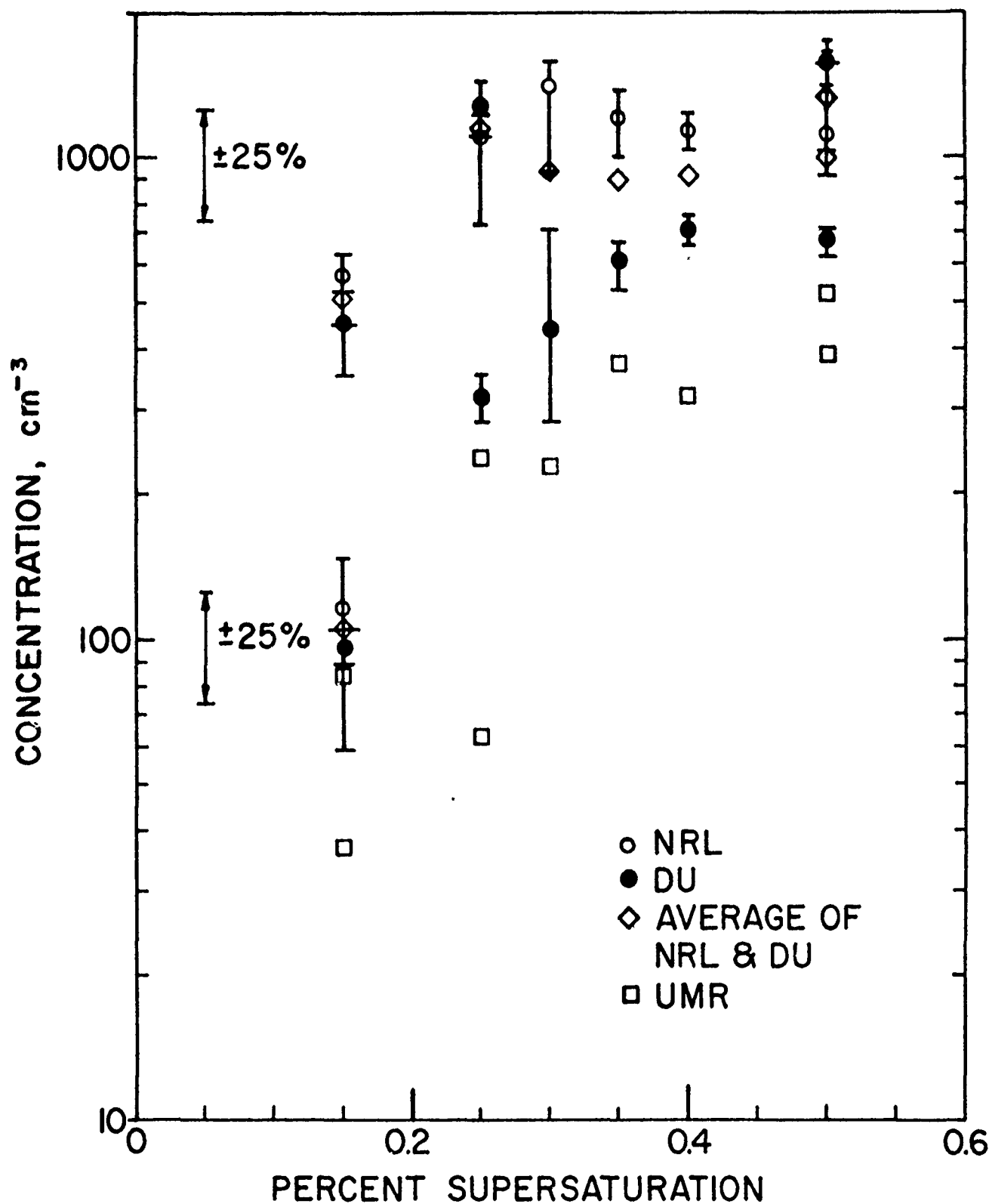


Fig. 2. Plot of CCN concentration as a function of supersaturation for the eight comparison runs. To each data point, an established value of the scatter is attached

would give the average over a certain time interval. Thus, for comparisons such as those made above, the scatter in the NRL values deserves due consideration.

2.2 Interconsistency of the spectrometer data

In the analysis of experimental errors, it is well understood (Meyer, 1975) that there exists three kinds of errors: random, systematic, and illegitimate. There is little purpose to reducing the contribution of the systematic error to the total uncertainty if most of the uncertainty is contributed by the random error. If the CCN concentration in the test sample is assumed uniform and the NRL measurements in Table 2 (column c) are taken as representative of random error that was as large as a factor (Max. value/Min. value) of 2.5, the agreement between the DU spectrometer and the NRL chamber may be regarded as satisfactory because the agreement is within a factor of 0.6 to 2.4 (Table 1). On the contrary, if the sample was non-uniform in CCN concentration, the average of the NRL values (column e) should be compared with the average of the available DU values (column h) that lead to an average deviation of $\pm 23\%$ from the mean. During the comparison runs, it was not possible to make as many measurements with the DU spectrometer at a given supersaturation as the NRL did because of the available limited volume of the test sample. Consideration of the average NRL values, reported in column 3 of Table 1, provides no idea of the magnitude of scatter in the data.

What counts is the narrowness of the frequency distribution as shown in Fig. 3. The shape of the frequency distribution is determined by the average error per measurement that, in turn, governs the value of the standard deviation (denoted by σ). The average error per measurement remains the same irrespective of the number of times a measurement is repeated. The error to be assigned (Meyer, 1975) to the result is the standard deviation of the mean: $\Delta\bar{x}$

$$\Delta\bar{x} = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{n(n-1)}},$$

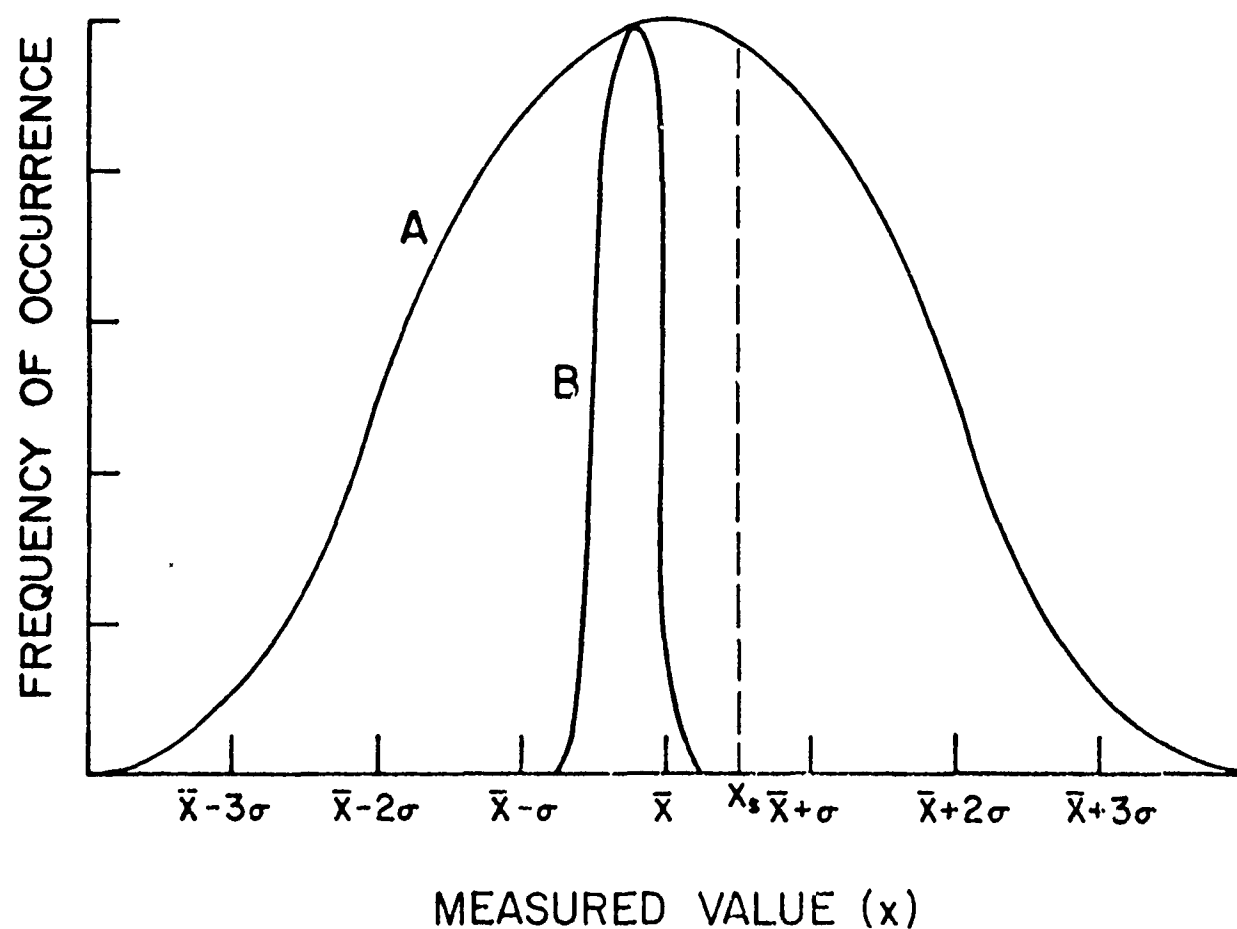


Fig. 3. Plot showing the importance of the narrowness of the frequency distribution in yielding standard value (x_s) of the measurement.
 \bar{x} , σ , respectively denote mean value and standard deviation.

where x_i is the value of the i th measurement ($i = 1, 2, \dots, n$), and \bar{x} is the mean of n measurements. Thus, the error assigned to the mean value of a restricted number of observations decreases as the number of observations increases, but only as the square root. A reduction by a factor of 10 in the average error of individual measurements produces the same improvement in the precision of the mean as do one hundred repetitions of the series of measurements.

The determination of the CCN spectrum by using static thermal diffusion chambers, such as that of NRL, is customarily made by taking only one measurement at one supersaturation in order to achieve a better resolution in time. Considering the sample as uniform in CCN concentration and the error as random, each value reported in column c of Table 2 at a given supersaturation is equally likely to occur. The DU spectrometer records the instantaneous CCN concentration and therefore any one value of column c of Table 2 should be compared with any one value of column f in Table 2. Figure 4 is based on this rationale. On the abscissa are plotted the NRL values marked by an asterisk in column c, and the values of column f are plotted against them. Such a plot is, of course, biased in favor of improving the agreement, nevertheless the rationale behind this figure is well taken. Figure 4 reveals that DU values lie within $\pm 19\%$ of the NRL value. This, of course, produces an unrealistically consistent set of data that may be just as incorrect as an inconsistent set.

From the above discussion, it follows that for the CCN spectrum determination, an instrument capable of measuring concentration within a wide frequency distribution (curve A in Fig. 3) around the "standard concentration (x_s)" will not yield better results than the instrument that produces values within a narrow range but consistently displaced from x_s (curve B in Fig. 3). This is exactly the reason why the DU spectrometer measures up to a high degree of interconsistency because of its inherent automatic operation for the spectrum determination.

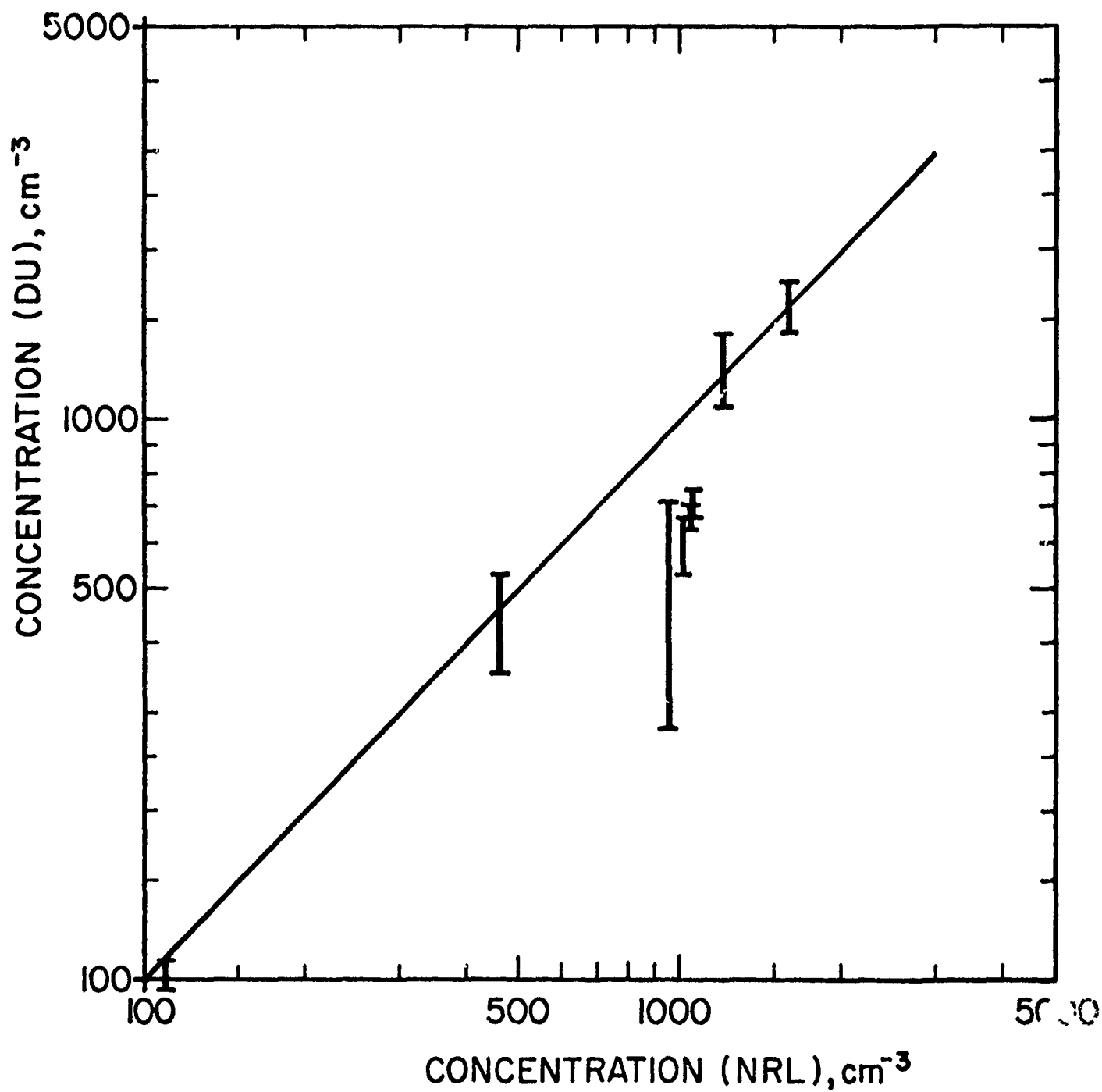


Fig. 4. Plot of the DU values against chosen individual NRL values. For complete agreement, the data points should lie on the straight line.

2.3 Case studies of fog episodes

The measurements taken during the Marine Fog Field Expedition of August, 1975 offer a unique opportunity to comprehensively study some fog episodes that were extensively monitored by various participants. Modeling of microphysics-dynamics interactions demand these measurements for a reasonable prediction of fog visibilities. After the CCN data are duly compiled, some case studies for modeling purposes will be undertaken. The physical model of marine advection fog presented by Fukuta (1973) emphasizes the importance of interaction between fog nuclei and the environmental change for arriving at realistic estimates of fog visibilities. Those fog episodes will be chosen for case studies that present dramatic variations in the fog nuclei spectrum while approaching the fog and getting out of fog. The main aim of putting the Fukuta-Saxena CCN Spectrometer aboard the Hayes was to monitor such variations. The spectrometer undoubtedly affords the best time resolution for such studies. This is made evident by the NRL measurements (Fitzgerald, 1975) of the CCN spectra as the latter were unable to detect any noticeable change in the fog spectrum during fog episodes. An example of the dramatic variations is presented below.

Let us consider Fog #4 that occurred during the early morning hours (2:00-8:00 A.M.) of August 6, 1975 off the Nova Scotia coast as shown in Fig. 5. The spectrum was monitored during the ship track, A-B-C-D-E. At point D (i.e., at 1:50 A.M.), the true wind direction was 340° . Thus, point D may be regarded as lying at the forming boundary of the fog. At point E, the wind direction was 13° , and it may be considered at the dissipating boundary of the fog. During the episode, the winds were mild to calm, the true wind speed varying from 0.4 (at 3:40 A.M.) to 14.7 knots (at 2:20 A.M.).

In Fig. 6 the visibility (β) is plotted as a function of time. The plot is based on the data provided by the NRL. To obtain the true value of visibility, the values of Fig. 6 should be divided by 1.65 within the fog (Jeck, 1975). The latter is the calibration factor. However, for our discussion the relative values of visibility will

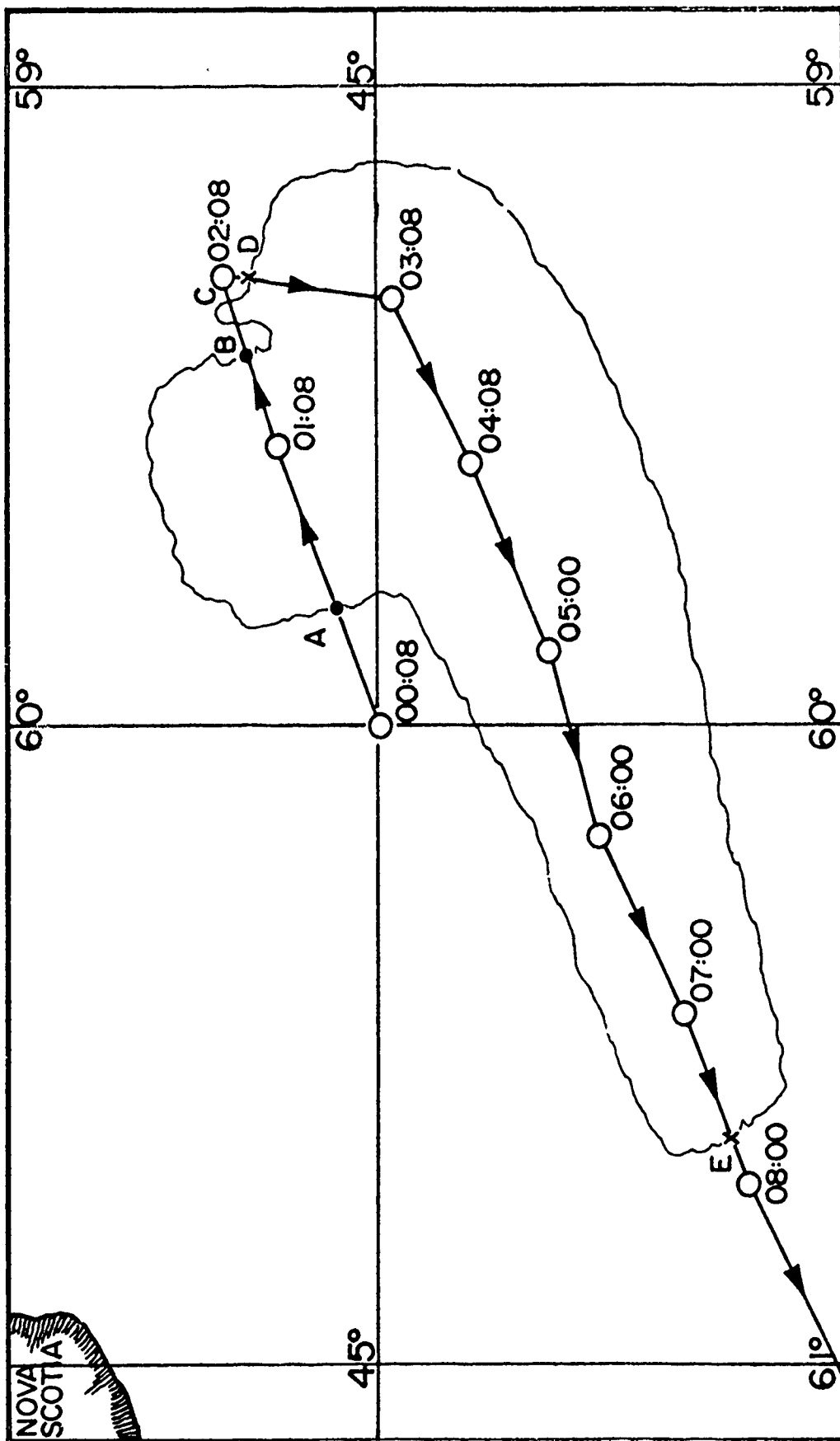


Fig. 5. Track of USNS HAYES in fog episode #4 that occurred during the early morning hours (2:00-8:00 A.M.) of August 6, 1975.

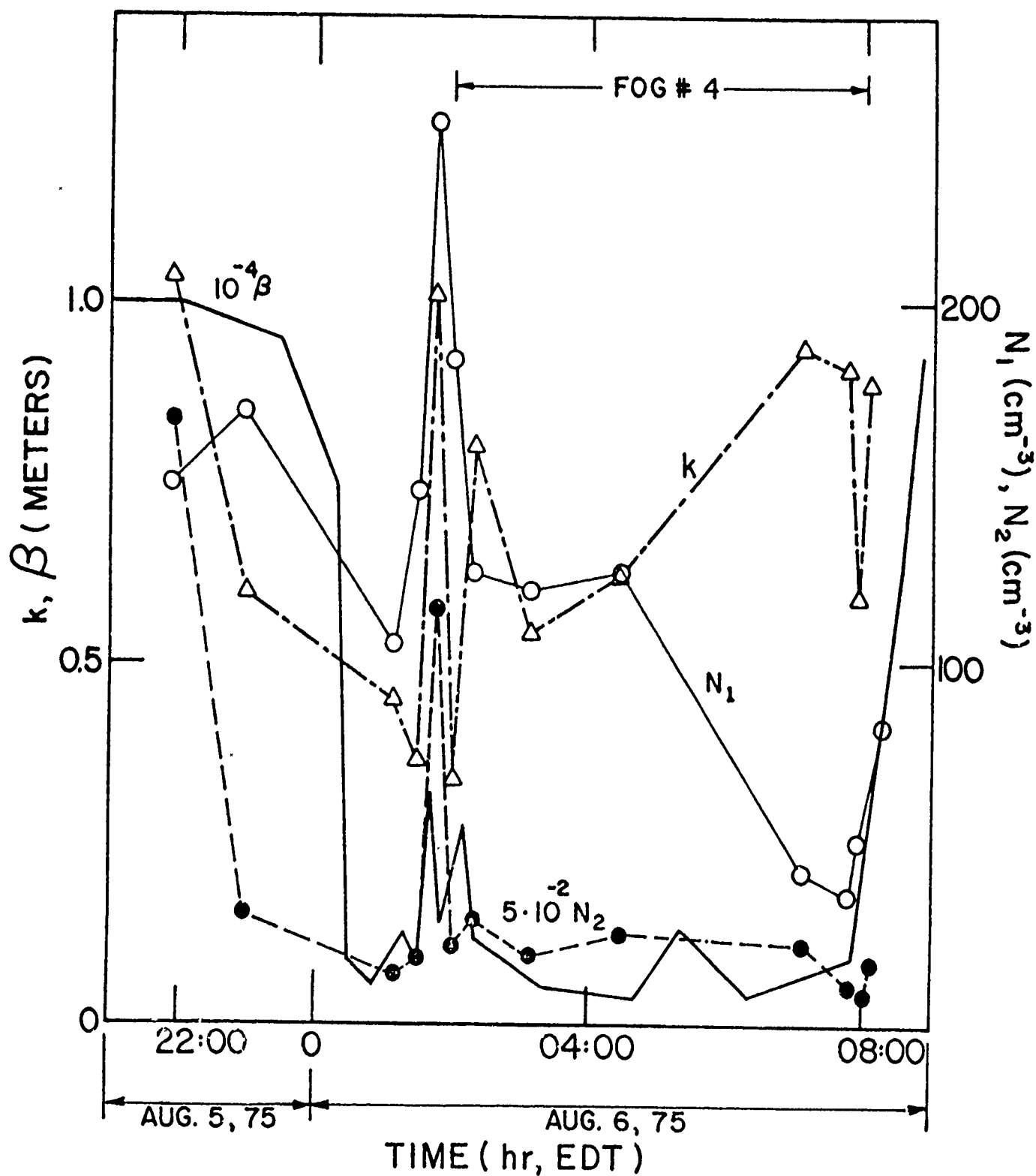


Fig. 6. Plot of visibility (β), nuclei concentrations at 0.15% (N_1) and 1.2% (N_2) supersaturations, and the slope (k) of the nuclei spectrum as a function of time for Fog #4. β is represented by a continuous thick line, k by dash-dot line, N_1 and N_2 by thin continuous line and broken line, respectively.

suffice. The fog nuclei spectrum recorded at different times during the episode was reduced to the form CS^k . In Table 5, the values of C and k are listed at different times. For these k -values, the nuclei concentrations in the supersaturation range of 0.15 to 1.2% were considered. In this supersaturation range, all droplets that grew beyond 1.0 μm diameter were counted. The spectrometer, however, sustained a supersaturation range of 0.06 to 1.2% and the droplets grown beyond 0.3 μm and 0.5 μm were also recorded. The latter data will be analyzed in the future in order to estimate fog nuclei concentrations active at supersaturations below 0.15%. The nuclei concentrations at 0.15% (N_1) and 1.2% (N_2) supersaturations are also recorded as a function of time in Table 5. The data of Table 5 are shown plotted in Fig. 6.

From Fig. 6, the dramatic variations in k , N_1 , and N_2 at the fog forming boundary are noteworthy. Just before 2:00 A.M. peaks in visibility (β), k , N_1 , and N_2 superimpose on each other. At the fog forming boundary, the nuclei concentration at 0.15% supersaturation drops by a factor of 1.35, while at 1.2% it drops by a factor of 6.0. The latter indicates a pronounced change that is beyond any kind of experimental error. The mechanism for this dramatic reduction in N_2 may be scavenging. These observations stress the need for monitoring the entire nuclei spectrum at the fog boundaries. Within the fog, the changes in N_1 , N_2 and k are not as dramatic but at the fog dissipating boundary, all these parameters show an upward trend and correlate well with the visibility. At the fog forming boundary, the absolute nuclei concentrations (for example, 2,500 cm^{-3} at $S = 1.2\%$) suggest that the aerosol that participated in the fog formation was continental in character. Such analysis is required for each fog episode in order to make the input data ready for a fog model that is capable of predicting fog visibilities. The final model will have to account for the scavenging effects of fog also. More case studies will shortly be made and a kinetic fog model to utilize these data is presently being developed. The kinetics of the fog formation (Fukuta and Saxena, 1973b) and nucleation-growth interactions (Fukuta and Walter, 1970; Nix and Fukuta, 1973) will be fully accounted for in such a model.

Table 5

Values of constant (C), slope (k), and nuclei concentrations at
0.15% (N_1) and 1.2% (N_2) supersaturations for Fog #4

Date	Time hr, EDT	C cm ⁻³	k	N_1 cm ⁻³	N_2 cm ⁻³
8/5/75	21:54	2,250	1.36	150	3,350
8/5/75	22:57	530	0.60	170	610
8/6/75	1:09	260	0.45	105	280
8/6/75	1:30	315	0.36	148	330
8/6/75	1:46	2,300	1.13	250	2,500
8/6/75	2:00	330	0.34	185	415
8/6/75	2:17	480	0.80	125	550
8/6/75	3:07	320	0.54	120	350
8/6/75	4:26	370	0.62	125	490
8/6/75	7:06	240	0.94	42	435
8/6/75	7:45	150	0.91	35	185
8/6/75	7:55	145	0.59	51	170
8/6/75	8:02	260	0.89	82	320

2.4 Ice nucleation properties and chemical nature of marine nuclei

One of the most interesting aspects of our participation in the Marine Fog Field Expedition was the exploration of the potential of our spectrometer for studying the ice nucleation properties and chemical nature of the marine fog nuclei. The valuable cooperation of Dr. R. C. Schnell of National Oceanic and Atmospheric Administration, Boulder, Colorado, and of Dr. R. E. Baier of Calspan Corporation, Buffalo, New York, resulted in such studies. For the purpose of these studies, the optical counter (Climet 201 sensor) was disconnected from the main chamber and the fog droplets that formed on the nuclei at the minimum and maximum test supersaturations were collected through a condenser arrangement in a test tube. The amount of fog water collected depends upon the time duration of collection, the CCN concentration in the sample, and the temperature difference between the median plane of the chamber and the surface of the collector. For our operating conditions, about half an hour was sufficient for collecting the sample for infrared spectrum analysis by Baier (1972), but for Schnell's drop freezing technique, a larger sample volume was required and consequently a lower time resolution could be achieved. A summary of these results is being worked out and will be made available shortly. It is interesting to note that some fog nuclei also behaved as freezing nuclei but this did not occur for all the samples. A careful analysis of these results is evidently warranted.

The infrared spectrum analysis of the samples was carried out by Baier using a Perkin-Elmer Model 700 Spectrometer which has also been used for extensive identification of the dominant chemical composition of sea-surface films, natural slicks, and foams (Baier et al, 1974). This indeed is a very useful technique and can be conveniently used in conjunction with our continuous flow spectrometer. Figure 7 displays two infrared spectra produced by Baier's technique. It is obvious that an absorption peak (corresponding to a dip in the transmittance) appears around the frequency of $\sim 1700 \text{ cm}^{-1}$. It is indicative of an organic ester-like material that was demonstrated by Baier to be water soluble. The

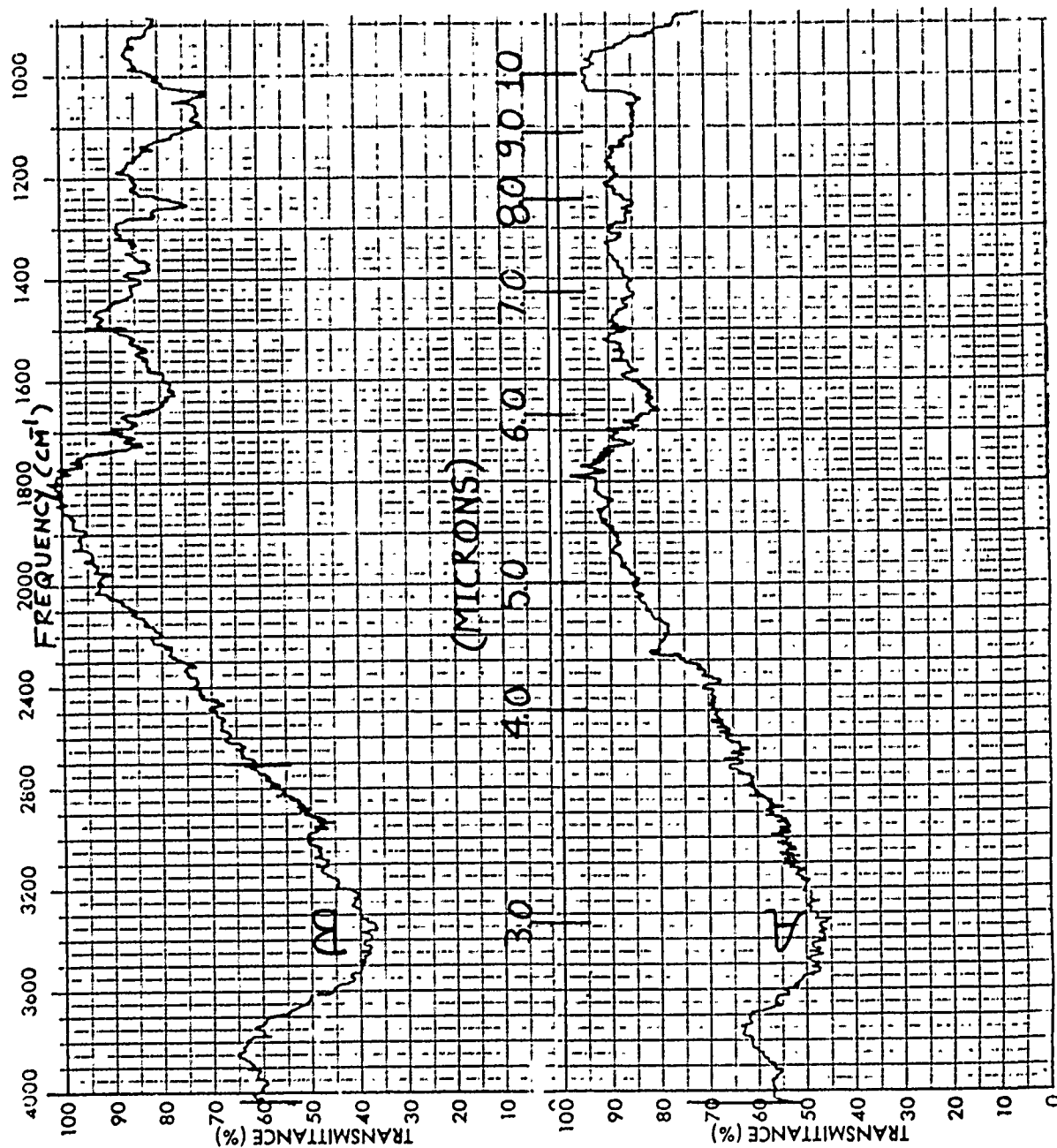


Fig. 7. Infrared spectra of fog water collected from the CCN Spectrometer: A - Supersaturation of ~0.15%, water collected at 10:45 EDT on August 10, 1975; B - Supersaturation of ~1.2%, water collected at 13:17 EDT on August 9, 1975. The air samples entering into the spectrometer were taken off the Newfoundland coast.

peak is pronounced in curve B in comparison to curve A. This leads to a tentative conclusion that more such material nucleates as higher supersaturations are encountered. Samples A and B were taken in the fog-free marine air. At present, it is hard to speculate the origin of this material. However, separate tests showed that it does not represent any impurity either in the collecting device or in the main chamber and is a characteristic of the incoming sample. Further work on these samples is in progress. Dr. Baier's work has already established that our spectrometer can be usefully employed for deriving information regarding the chemical nature of fog nuclei through the infrared spectrum analysis.

3. CONCLUSIONS AND RECOMMENDATIONS

The Marine Fog Field Expedition sponsored by the Naval Air Systems Command and organized by the Naval Research Laboratory during July-August, 1975 was one of the most successful experimental programs motivated to understand the complex fog phenomena. Our participation resulted in extensive measurements of the activation spectrum of fog nuclei. The following conclusions seem to be reasonable on the basis of our study.

1. For the prediction of fog visibility, it is imperative to estimate the concentration and size distribution of droplets that comprise the fog. Such an estimation demands the knowledge of the activation spectrum of fog nuclei.

2. Our case study shows a profound change in the fog nuclei spectrum at the fog forming boundary, the change was less dramatic at the dissipating boundary. Nevertheless, a definite change in the activation spectrum was observed at both fog boundaries. From a theoretical standpoint, such a change was anticipated on the basis of a kinetic fog model (Fukuta and Saxena, 1973b; Fukuta, 1973, 1974).

3. The fog was demonstrated to be an efficient scavenger of cloud condensation nuclei active at 1.2% supersaturation and below. A complete fog model should include the operative scavenging mechanisms also.

4. In some fog episodes, the nuclei concentrations were typical of a continental aerosol that evidently participated in the marine fog formation.

5. A comparison of our spectrometer data with that obtained by the Naval Research Laboratory static chamber showed that the agreement between the two was the same as the agreement between the NRL chamber and other static thermal diffusion chambers compared so far. This is a very gratifying result, particularly when one recalls the difference between the counting techniques employed in the two devices. Our spectrometer records instantaneous concentration while the NRL chamber produces "average" values.

6. Some tests on the fog water collected from our spectrometer showed that the fog-free marine air contained some CCN that may also be potential freezing nuclei. These tests were conducted in cooperation with Dr. R. C. Schnell.

7. The infrared spectrum of the fog water collected from our spectrometer indicated that the CCN in the fog-free marine air contained organic ester-like material that was shown to be water soluble. These experiments were done in cooperation with Dr. R. E. Baier and further studies on the subject are in progress.

It is highly recommended that the data collected during the expedition should be fully analyzed in terms of a fog model that accounts for the microphysics-dynamics interactions. The prediction of fog visibilities heavily depends upon the availability of such a model. The data collected during the expedition afford a unique opportunity of verifying the predictions of the model since simultaneous viscometer observations are available for various fog episodes. The analysis of the available data in terms of a comprehensive fog model will also help plan future field expeditions efficiently.

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